NASA TECH BRIEF

Study Made of Interaction Between Sound Fields and Structural Vibrations

"Sound and Structural Vibration," by Preston W. Smith, Jr., and Richard H. Lyon, Bolt, Beranek, and Newman, Inc., Cambridge, Mass., NASA CR-160, March 1965.

This report is designed to be a systematic development of some new techniques for analyzing structural vibrations and the interactions between sound fields and structural vibrations. In its application to structural vibration, the approach is quite new, having been motivated by the lengthening roster of difficult questions concerning vibrations in very complicated structures—buildings, missiles, ocean vessels, etc.—which are caused by a complicated set of forces.

In the classical approach to a vibration problem, one usually asks, "What is the dynamic displacement of a particular point at a particular instant?" Now, in many practical problems, this is an unreasonable question because *particular* points and *particular* instants are not really of concern, and a collection of data for *all* points and *all* instants would be overwhelming.

To get a useful answer, some different question must be posed: "What is the average dynamic response (in a root-mean-square sense) when that average is performed both in space and in time?" This is better because the answer is one handy number. However, too much information has been lost in the process.

The nature of the problem and some idea of the answers desired can be brought out by describing a typical practical situation. A very large rocket carries a moderately large capsule inside of which are mounted, in various ways and positions, some packages of delicate electronic instruments. Too much vibration of any one of many vacuum tubes, for example, will cause the whole rocket to misbehave. It is thought that the vibration may be caused by sound from the rocket engine passing through the capsule and reverberating about inside. An estimate of the vibration generated in this manner is desired so that possible protective modifications to the structure and the instruments can be evaluated in a rational manner.

The sound inside the capsule is found to be an extremely complicated function of time. It is a more or less random noise, although the energy is not distributed uniformly in frequency. Moreover, because of the limited space in the capsule, sound does not reach the package from any single direction. The sound bounces around in the space, and is repeatedly reflected from many different angles, which markedly affects the spatial distribution of force on the package.

The vibratory response of the package to sound waves can be studied in the laboratory, irradiating it with a pure-tone wave incident from a single direction. One will then typically find that the response at a single point fluctuates tremendously as frequency is varied, being very large in small regions of frequency near the natural mechanical resonances of the package. At any one of these natural frequencies, the response may vary quite considerably, depending upon the angle from which the sound wave arrives. Finally, the magnitude of response varies from point to point, when frequency and angle of incidence are held fixed.

Upon inquiry, one discovers that the various electronic elements are sensitive to vibration in various ranges of frequency, and that their exact locations either are not known, are subject to change, or are distributed widely throughout the package. It is now evident that no exact question can be posed; it is needless to search for exact answers, of the type we called "classical". Only some sort of average, statistical estimates of response are required.

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In this report analytical procedures are developed for obtaining estimates of this sort. In crude outline, the procedures more or less parallel the experimental laboratory study just described. From design drawings, one estimates the average number of resonances expected in a moderately broad band of frequency and the spatial distribution of response amplitude for a "typical" mode of resonance. With this information, one estimates the average response of a single "typical" mode to sound waves of noise incident from many various angles. The product of this average response per resonant mode by the average number of modes in a frequency band yields an estimate for the space-time average response in that frequency band. The process is repeated for different bands.

It is, of course, hopeless to attempt to find the exact characteristics of individual modes in the early phases of such an analysis. The saving feature of this new approach is that many of the average characteristics—number of modes in a frequency band, average coupling to sound incident from various angles, etc.—are insensitive to those details of construction which render impossible the exact analysis.

The aims of the present study are three-fold: (1) To outline a conceptual framework for analyzing the vibrations of complex distributed systems and the interactions of several systems. The approach proceeds by (a) a multimodal description of the vibrations of a system; (b) characterization of the modal response by the vibratory energy involved, and of the interactions by energy flux; and (c) formulation of statistical average estimates of the dynamic parameters of various systems. (2) To incorporate the principal results of earlier studies of vibratory interactions between sound fields and bending vibration fields in panel-like structures. (3) To establish a unified basis for continuing research and extensions to new problems.

Notes:

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2. Inquiries concerning this invention may be directed to:

   Technology Utilization Officer
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Patent status:

Inquiries about obtaining rights for the commercial use of this invention may be made to NASA, Code GP, Washington, D.C. 20546.

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